

Food and Nutrition for the Moon Base

What We Have Learned in 45 Years of Spaceflight

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Introduction—History of Human Space Flight—Food and Nutrition

The United States has a new human spaceflight mission—to return to the Moon, this time to establish an outpost to continue research there and develop our ability to send humans to Mars and bring them back in good health. The Apollo missions were the first human expeditions to the Moon. Only 2 crew members landed on the lunar surface on each Apollo mission, and they spent a maximum of 72 hours there.¹ Future trips will have at least 4 crew members, and the initial trips will include several days of surface activity. Eventually, these short (sortie) missions will extend to longer stays on the lunar surface, on the order of weeks. Thus, the challenges of meeting the food and nutritional needs of crew members at a lunar outpost will be significantly different from those during the early Apollo missions. Provisioning the crews at a lunar outpost will be challenging.¹

The United States has had humans in space beginning in 1961 with increasing lengths of time in spaceflight (Table 1). Throughout these flights, the areas of particular concern for nutrition are body mass, bone health, and radiation protection. The development and refinement of the food systems over the last 30 years are discussed, as well as the plans for both the sortie and longer lunar surface operations.

This article briefly reviews what we know today about food and nutrition for space travelers and relate this knowledge to our planned human flights back to the Moon (Figure 1).

Changes in Nutritional Issues Over the Last 45 Years

Body Weight Changes, Food Intake, and Energy Utilization

Energy utilization and food intake^{2–5} were measured in many of the US space programs. Throughout these

various space missions, food intake has been estimated using either food records or food frequency questionnaires.^{2–5} Energy utilization research used a variety of methods including indirect calorimetry method of doubly labeled water.^{3,4} These results confirmed that energy utilization levels can be predicted using the World Health Organization calculations using moderate activity. Results show that astronauts, except for those on Skylab space station in the 1970s, had daily in-flight food intakes below those calculated necessary to meet energy needs. As a result, body weight loss has been common in astronauts (Figure 2). During 2000 to 2004 on the early International Space Station (ISS) medical care program (128- to 185-day durations), 11 astronauts had lean body mass reductions from 56.2 ± 7.2 to 55.1 ± 8.3 kg and fat mass reductions from 15.3 ± 3.6 to 14.7 ± 3.4 kg, with body weight changes between 5% and 10% of preflight body weight.⁵ Generally, astronauts lose lean body mass as well as fat mass during spaceflight; this is most likely related to negative energy balance and weight loss. The National Aeronautics and Space Administration provides foods that provide energy at levels equivalent to the World Health Organization calculation using moderate activity levels.

The ISS medical care program instituted a weekly measurement of food consumption using a specially designed space food frequency questionnaire. The questionnaire was validated through ground-based studies with foods similar to those supplied to the ISS crew members.⁶ Food frequency questionnaires are a good method of estimating food intake when the number of food items is limited and a closed inventory system is used, as on the ISS. If a crew member has inadequate energy consumption, the medical doctor is notified, and recommendations are made to improve intake. This system has improved the food intakes of crew members on the ISS.

It is not clear why energy utilization is similar between Earth and space activities, especially in microgravity, because the astronaut is not walking against a gravitational force. On Earth, it would seem that

Table 1. Summary of the US Human Space Flight Programs

Year	Human Space Flight Program	Flight Length
1961–1963	Mercury	15 min to 34 h
1965–1966	Gemini	5 h to 14 d
1968–1972	Apollo	5–13 d
1973–1974	Skylab Space Station	28, 59, and 84 d
1981–present	Space Shuttle	4–15 d
1995–1998	Shuttle-Mir Space Station	4–6 mo
2000–present	International Space Station	5–7 mo

more energy is required for walking compared with floating in space. However, energy utilization measured by a variety of methods demonstrates that energy needs in spaceflight are the same as on Earth.^{3,4} Although the exercise is not similar to that on Earth, the astronauts do move and use their limbs to move around. There is also some indication that basal energy utilization is increased during spaceflight, and endocrine changes (such as increased cortisol levels) may increase metabolic rates.⁷ Interestingly, the energy consumption measured during the lunar extravehicular activities was lower than energy utilization in underwater—neutral buoyancy—training.⁷

Musculoskeletal Changes

Spaceflight has a significant negative impact on the musculoskeletal system. Losses of muscle volume and strength are routinely reported.^{8–10} For instance, after only 15 days in flight, astronauts had an 8% loss of hamstring volume, a 6% loss of quadriceps volume, and

a loss of more than 10% in the intrinsic lumbar region muscles. Various exercises are used to decrease muscle losses, including resistance exercises.¹⁰ Resistance exercise with adequate food intake may prevent loss of muscle function (and bone mass) during spaceflight.¹¹ It is assumed that these levels of exercise will be needed to maintain fitness for long-duration spaceflight.

Even during the best nutritional conditions with very little loss of body weight, the astronauts on Skylab missions were in negative nitrogen balance.¹² These astronauts routinely completed heavy aerobic exercises. Although consumption of hypocaloric diets decreases protein synthesis, it is not the only mechanism for loss of muscle mass. Several studies of astronauts indicate elevated blood and urinary cortisol levels suggesting elevated metabolism as a potential mechanism for muscle losses. One protein turnover study with astronauts on the Russian space station, Mir, showed increased protein turnover.¹³

Ground-based studies with simulated microgravity—bed rest—indicate that there may be a decrease in protein synthesis in the presence of adequate energy intake^{14,15} and increased insulin insensitivity. Exercise, especially with resistance protocols, has ameliorated some of these changes. During tours on the ISS, astronauts participate in aerobic and resistance exercises at a level that maintains aerobic capacity and muscle strength. Some research indicates that a high-protein diet, especially high in essential amino acids, will improve protein synthesis for maintaining muscle mass and function.^{3,4} In these studies, bed rest subjects had increased protein synthesis and reduced muscle and strength loss with an essential amino acid supplement. These researchers suggest that the combination of exercise and an amino acid supplement will prevent the increases in protein turnover and maintain muscle functions. However, this protocol of amino acid supplementation increased bone resorption markers that indicate increased bone losses.^{16,17}

In contrast to the muscle countermeasures, interventions tried, to date, have not helped prevent

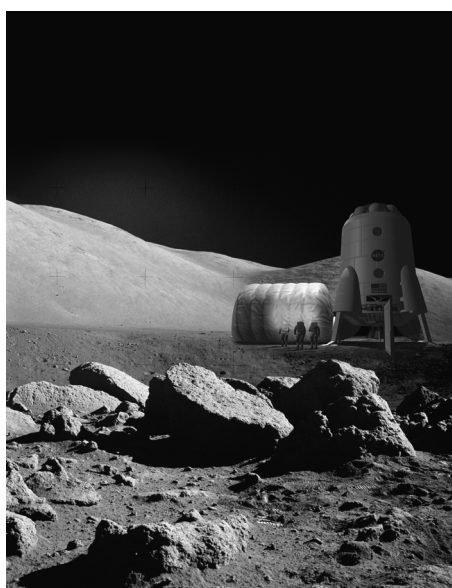


Figure 1. Illustration of lunar base.

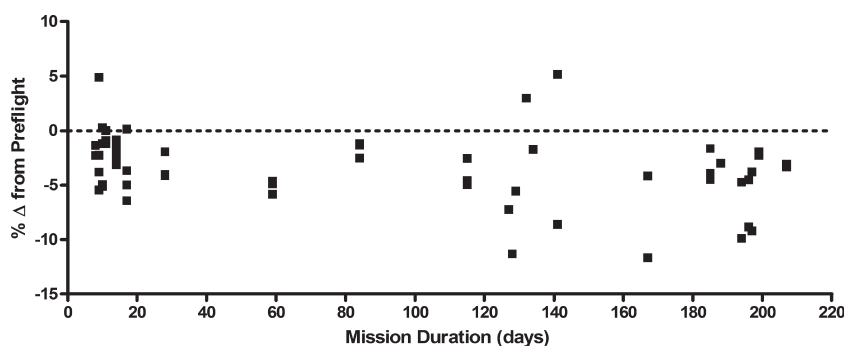


Figure 2. Postflight weight loss in astronauts on Shuttle, Skylab, Mir, and ISS flights. Data are expressed as percent change in body weight at landing compared with preflight.

bone loss during spaceflight.^{17,18} All astronauts on long-duration missions lose bone mineral density in at least 1 region (such as spine, hip, or femoral neck), but subject-to-subject variability in response to flight is large.¹⁹ Recent research showed that loss of trabecular (spongy) bone was greater than loss of cortical bone (the outer layer of compact bone).²⁰ This is an important observation for the development of methods designed to prevent bone loss during flight, as well as the development of rehabilitation protocols after spaceflight.

The astronauts on the Skylab missions, who had adequate food and exercise, also had increased excretion of bone resorption markers throughout their missions.²¹ Preflight and postflight assessments of ISS astronauts indicated that their bone resorption markers remained elevated on landing day.⁵ Smith et al²² used stable isotopes to study calcium homeostasis of 6 long-duration-Mir crew members. Their results suggest that around 250 mg of calcium is lost from bone per day during flight and that although this loss was reversed after landing, it would take 2 to 3 times longer than the mission to regain the lost calcium. Ground-based studies suggest that dietary factors, including dietary sodium intake and the ratio of animal protein intake to potassium in the diet, may affect bone health.²³

Nutrition plays an important role in bone health in spaceflight as well as on Earth. Because of lack of sunlight, the synthesis of vitamin D decreases during spaceflight. The 3 crew members who flew on Skylab for 84 days had lower serum concentrations of 25-hydroxyvitamin D during flight than before flight.¹² Crew members who flew long-duration missions on the Russian Space Station Mir for 115 to 195 days had similar decreases.^{22,24} Compared with preflight concentrations, their parathyroid hormone also decreased during flight and increased after flight.⁶ Markers of bone resorption (such as urinary N-telopeptide and

pyridinium crosslinks) significantly increased during and after flight.^{5,21}

An important objective of ongoing research is to develop exercise, pharmacological and dietary treatments to prevent losses in musculoskeletal function. In addition, centrifugation as a source of “artificial gravity” is being tested on subjects undergoing bed rest to help determine if the one-sixth gravity of the Moon will be beneficial to the retention of muscle or bone mass. Another prevention strategy is use of lower body negative pressure in conjunction with treadmill exercise with bed rest subjects. Bed rest mimics the lack of gravitational force, and the lower body negative pressure mimics gravity’s pull. In microgravity, the gravity that pulls body fluids toward the feet is very weak. In a bed rest study with multiple sets of identical twins, bone resorption markers significantly decreased in the twins who received the lower body negative pressure/exercise treatment.²⁵

Radiation and Nutrition

A major hazard of space travel is radiation exposure. For regulatory purposes, astronauts are considered radiation workers. The Earth’s atmosphere provides some radiation protection. An individual living at a high altitude (as in Denver) will have 200 times less radiation exposure than an astronaut in space. Moon radiation includes both galactic cosmic rays and solar particle events (sun flares).²⁶ Radiation exposure on the Moon is more dangerous than on the Shuttle or ISS. Radiation exposure of astronauts during spacewalks (extravehicular activity) is also a concern²⁶ because the space suit offers minimal protection.

Radiation can cause chromosome and DNA damage, including single- and double-strand breaks, deletion of nitrogenous bases, and rupture of hydrogen bonds.^{27,28} Studies show that single-strand DNA breaks can be

repaired or rejoined; therefore, maintaining proper DNA repair is an important mechanism for preventing cell destruction and DNA mutation leading to cancer. Also, ionizing radiation interacts with cell components to produce free radicals. Because of radiation exposure, astronauts are at greater risk of developing cataracts, altered central nervous system function, and changes in bone stem cell production. Radiation exposure, in general, can increase the incidence of cancers, skin cancer in particular, and can affect fertility.

One marker of oxidative damage to DNA is 8-hydroxydeoxyguanosine, excretions of which were significantly increased after long-duration spaceflight.⁶ A marker for increased peroxidation is superoxide dismutase, an intermediate enzyme in the metabolism of free radical ions in water. In the same study,⁵ superoxide dismutase was lower on landing day than before flight.

Food components such as antioxidants, omega 3 fatty acids,²⁹ and even dietary plant fiber may prevent and/or ameliorate radiation damage. Numerous animal studies with ionizing radiation suggest that dietary components may prevent some of the radiation-induced damage. The next step is to determine the ability of these dietary compounds to mitigate space radiation risks.

Summary of Nutrition Research

The prospect of a lunar outpost to conduct science and learn how to live and work off the Earth is exciting. The nutritional sciences will focus on the issues of overall health, with emphasis on skeletal muscle health and prevention of radiation damage. There is a great deal of research needed to determine the nutritional and food component potential for preventing the changes that occur in spaceflight. Further research is also needed on the interactions of systems and countermeasures, such as protein amino acid needs for enhancement of muscle protein synthesis while not being detrimental for bone health. The interrelationship between radiation exposure, nutrition, and food components has just begun.

Changes in Space Food Over the Last 45 Years

First Trip to the Moon—Apollo Missions

From 1969 through 1972, 12 US astronauts made 6 landings on the Moon.³⁰ A variety of foods—dehydrated foods hydrated with hot water, food preserved in thermostabilized pouches, some tube foods, and bite-sized foods—was available to the astronauts. However, the astronauts often did not take the time to consume the food, and they did not particularly like



Figure 3. Example of foods.

some of these items.^{30–32} The nutritional values of the food reflected the recommended dietary allowances of the time period. For instance, calcium intake was recommended at 800 mg/d. During the Apollo program, the food system improved, and many of the developments led to the Shuttle and ISS food systems.

The Most Advanced US Space Food System—Skylab Space Station

In the early 1970s, the United States launched its first space station, Skylab, which was dedicated to solar astronomy and life sciences research.³³ Astronauts lived and worked on Skylab for 3 missions of 28, 59, and 84 days. They had a large interior living area with a dining room and table. They had eating utensils and a pair of scissors to cut open food containers. The containers were similar to plastic bowls. The 72 different foods that were provided in plastic bowls included frozen and refrigerated foods. No other US food system had this quality of foods. Skylab astronauts participated in metabolic studies and were strongly encouraged to consume all their foods. Consequently, Skylab is the only space program in which astronauts did not lose weight. Repeating these metabolic experiments with the current food program is not expected to occur for many years because of power and volume constraints imposed on current US and Russian space vehicles and emphasis on other science objectives.

Shuttle and ISS Food Systems

Space Shuttle and Station foods differ owing to mission constraints.

In current spaceflight programs, basic foods must be stored at ambient temperatures, survive acceleration

and temperature gradients during launch, and meet safety and nutritional standards. Many of the foods used are commercially available but are packed for individual consumption with protection such as oxygen barriers. The foods are reheated by radiant heat because convection currents do not occur in the microgravity of spaceflight. Packages are flat for ease of storage (Figure 3). Food components are freeze-dried, thermostabilized (made to be unaffected by heating), irradiated, or left in a natural form (nuts are an example of the latter). Infrequently, some fresh foods, such as fruits, are available. Crew

members select their flight menu by tasting foods before launch, and menus are determined to provide variety and meet nutritional requirements (Table 2).³⁴

The Shuttle and ISS foods differ in several major ways. The Shuttle can handle dehydrated foods better because water is readily available as a by-product of the fuel cells that provide the Shuttle's power (Figure 4). ISS power comes from solar panels; hence, water is a limited resource. Thus, ISS has a higher percentage of thermostabilized foods, which already contain the necessary water.

Table 2. Example of Space Flight Menus

Meal	Day 1	Day 2	Day 3
Breakfast	Blueberry/Raspberry Yogurt (T) Granola with Blueberries (R) Orange Drink (B) Kona Coffee with Cream, Sugar (B)	Dried Peaches (IM) Oatmeal with Raisins (R) Orange Drink (B) Kona Coffee with Cream, Sugar (B)	Blueberry-Raspberry Yogurt (T) Granola with Raisins (R) Orange Drink (B) Kona Coffee with Cream, Sugar (B)
Lunch	Beef Fajitas (I) Tortilla (FF) ×2 Applesauce (I) Almonds (NF) Lemonade (B) ×2	Smoked Turkey (I) Tortillas (FF) ×2 Dried Pears (IM) Almonds (NF) Orange-Grapefruit Drink (B) ×2	Chicken Strips in Salsa (T) Tortillas (FF) ×2 Applesauce (T) Cashews (NF) Lemonade (B) ×2
Dinner	Shrimp cocktail (R) Grilled Chicken (T) Macaroni and Cheese (R) Green Beans with Mushrooms (R) Candy Coated Chocolates (NF) Lemonade (B) Tea with Lemon and Sugar (B)	Vegetarian Vegetable Soup (T) Chicken Fajitas (T) Tortilla (FF) ×2 Cherry-Blueberry Cobbler (T) Orange Drink (B) Tea with Lemon and Sugar (B)	Chicken Noodle Soup (T) Beef Stroganoff w/ Noodles (R) Broccoli au Gratin (R) Dried Peaches (IM) Apple Cider (B) Tea with Lemon and Sugar (B)
	Day 4	Day 5	Day 6
Breakfast	Dried Pears (IM) Oatmeal with Brown Sugar (R) Orange Drink (B) Kona Coffee with Cream, Sugar (B)	Dried Peaches (IM) Oatmeal with Raisins (R) Orange Drink (B) Kona Coffee with Cream, Sugar (B)	Blueberry-Raspberry Yogurt (R) Granola Bar (NF) ×2 Dried Peaches (IM) Orange Drink (B) Kona Coffee with Cream, Sugar (B)
Lunch	Peanut Butter (T) Grape Jelly (T) Tortilla (FF) ×2 Trail Mix (IM) Grape Drink (B) ×2	Beef Fajitas (I) Tortilla (FF) ×2 Dried Pears (IM) Almonds (NF) Orange-Grapefruit Drink (B) ×2	Chocolate Brownie Clif Bar (FF) Vanilla Breakfast Drink (B) Almonds (NF) Orange-Mango Drink (B)
Dinner	Shrimp Cocktail (R) Crawfish Etouffee (T) Vegetable Risotto (R) Creamed Spinach (R) Dried Peaches (IM) Apple Cider (B) Tea with Lemon and Sugar (B)	Grilled Pork Chop (T) Mashed Potatoes (R) Broccoli au Gratin (R) Peach Ambrosia (R) Apple Cider (B) Tea with Lemon and Sugar (B)	Split Pea Soup (T) Teriyaki Chicken (R) Rice Pilaf (R) Broccoli au Gratin (R) Peach Ambrosia (R) Apple Cider (B) Tea with Lemon and Sugar (B)

B indicates beverage; FF, fresh food; I, irradiated; IM, intermediate moisture; NF, natural form; R, rehydratable; T, thermostabilized.



Figure 4. Astronaut James H. Newman, PhD, consuming foods on Space Shuttle.

Shuttle missions (Figures 5 and 6) last approximately 2 weeks, whereas ISS missions last 6 months. With longer missions, acceptability of the food by the astronauts is much more important. Anecdotal reports from the crew suggest that the sense of taste changes in microgravity. Because approximately 85% of what you taste is what you smell, it is not clear whether this phenomenon is due to fluid shift in the body, vehicle air currents where hot air does not rise, or the fact that the food is not piping hot in temperature. The observed effect could also be related to the fact that the crew is far from home, and they may be missing “comfort foods.” Related to acceptability, the ISS crews require more variety in their menus because of the longer flights (Figure 7). For the initial ISS flights, the menu cycle was 6 days. The menu cycle has gradually increased, and the crew currently experiences a 10-day cycle menu cycle.

With increasing duration of flights, both acceptability and variety become more important, and the National Aeronautics and Space Administration food scientists have developed 65 new foods for the ISS menu. Because there is a need for more flavors to counteract the change in taste and because the crew members train in Houston (known for its ethnic and spicy foods), the new food items are flavorful and spicy. In addition, the foods are ethnic in nature and include Chinese, Indian, Cajun, and Mexican menu items. However, the favorite among many of the astronauts is still the freeze-dried shrimp cocktail with its flavorful cocktail sauce.

The Shuttle launches with all the crew members' foods, including some fresh foods, but ISS food may be launched separately from the crew members and does not contain fresh foods. Supplies of fresh foods are provided to ISS crew members infrequently via the Russian

Progress resupply vehicles or the Shuttles when they dock with the ISS. Sometimes, because of changes in launch dates of supply missions, ISS crew members do not have the food items they chose for their menus. On the ISS, food is stored in boxes and sorted by categories, like a kitchen pantry, allowing the crew members to select their foods of choice. This provides the crew with some choice on what to eat during each meal—another psychological boost during the long mission.

Foods for Return to the Moon

Initially, sortie missions to the Moon will have a total duration of 2 weeks, and astronauts will spend approximately 7 days on the surface. For these missions, the food system will be similar to that of the ISS. However, the sortie mission crew compartment will have less space than the ISS for heating and eating foods, as well as for trash containers. No waste disposal system will be available, so food packaging must be disposed of in some other way. Because the present plan is to return all waste to Earth, the packaging must not only provide a sufficient barrier to oxygen and water but also have low mass and volume.³⁵

There are plans for the establishment of a habitat on the lunar surface. A habitat would allow the food system



Figure 5. Shuttle launch.

to be expanded to include some in situ-grown foods such as salad crops (Figure 8) and provide a potential for some food preparation similar to that on Earth. If a long-duration Moon base is built, a greater variety of foods will be provided by growing, or bringing up in bulk, crops such as soybeans, wheat, peanuts, beans, and rice. This would lead to a more vegetarian-like diet. Most of these crops would require some food processing and cooking capabilities for long-duration extraterrestrial missions.

Although small amounts of green leafy foods such as lettuce have been grown on the Russian Space Station Mir, US Shuttle flights, and the ISS, technical issues make it difficult to grow plants on the Moon. The atmosphere of the Moon base will probably have a higher percentage of oxygen and carbon dioxide (CO₂) than on Earth, at an atmospheric pressure between 8 and 10.2 psi rather than the 14.7 psi on Earth. The elevated CO₂ levels would tend to increase photosynthetic rates for many crops and improve yields.^{36,37} Although the percentage of oxygen might be high because of reduced overall pressure, this should not interfere with photosynthesis so long as the absolute partial pressure of CO₂ is greater than 0.1 kPa, or the equivalent of 1,000 ppm at 14.7 psi total pressure.^{36,37} As with all gases, diffusion of water vapor at reduced pressures would increase, resulting in increased rates of transpiration.^{38,39}

Plants for food production on the Moon would likely be grown in their own chambers so that the atmospheric mixture of oxygen, CO₂, and humidity, along with temperature, light levels, and light cycles, can be controlled. At the same time, the plants will be growing at one sixth of Earth gravity. Although these gravitational forces are less than on Earth, they are greater than in space. Will this partial gravity affect crop growth compared with the growth in microgravity of spaceflight or the 1 gravity of Earth? Partial gravity of the Moon should at least allow the use of conventional watering



Figure 7. International Space Station.

techniques, similar to those on Earth, but clearly, it will be a challenge to grow crops at sustainable levels on the Moon.

Crop processing and food preparation techniques will be limited on the Moon, even with the slight increase in gravity, more room, and potentially adequate power. The heating and processing of food will require food processing equipment that uses a limited amount of water (continuing to be a limited resource) and crew time. Because launch mass and volume are constraints, all food processing equipment must be multifunctional. By self-containing the equipment, the contamination from dust and the effects of lower atmospheric pressure on the processing of the food will be minimized (Figure 6–8).

Summary of Food System

The space food system has improved over the last 45 years. With the advances for a Moon base, there

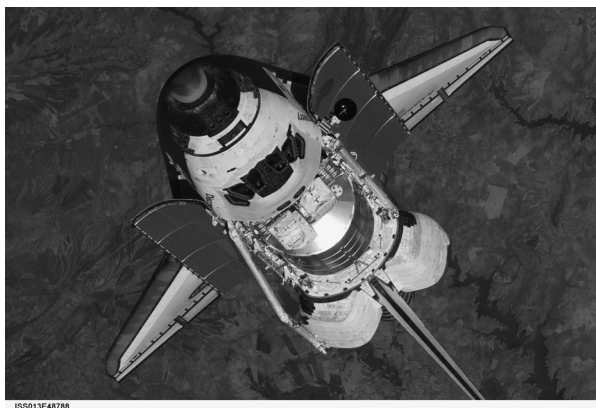


Figure 6. Shuttle orbiting the Earth.



Figure 8. Illustration of foods growing at a Moon base.

is a potential that foods in space will be more like home-cooked foods. However, until that happens, dehydrated and thermostabilized foods will continue to exist, providing the bulk of the astronauts' food. For the astronauts to have adequate macronutrients, a food system must be developed including raising plants and food preparation, both a major challenge given the limited water, volume, and power. The lunar kitchens will be very different, but good food is essential to maintain good health.

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REFERENCES

- Johnston RS, Dietlein LF, Berry CA, eds. *Biomedical Results of Apollo (NASA SP-368)*. Washington, DC: National Aeronautics and Space Administration; 1975.
- Leach C, Alfrey C, Suki W, et al. Regulation of body fluid compartments during short-term spaceflight. *J Appl Physiol*. 1996;81:105–116.
- Lane HW, Gretebeck RJ, Schoeller DA, Davis-Street J, Socki RA, Gibson EK. Comparison of ground-based and space flight energy expenditure and water turnover in middle-aged healthy male US astronauts. *Am J Clin Nutr*. 1997;65:4–12.
- Stein TP, Leskiw MJ, Schluter MD, et al. Energy expenditure and balance during spaceflight on the space shuttle. *Am J Physiol*. 1999;276:R1739–R1748.
- Smith SM, Zwart SR, Block G, Rice BL, Davis-Street JE. Nutritional status assessment of International Space Station crew members. *J Nutr*. 2005;135:437–443.
- Smith SM, Davis-Street JE, Rice BL, Nillen JL, Gillman PL, Block G. Nutritional status assessment in semiclosed environments: ground-based and space flight studies in humans. *J Nutr*. 2001;131:2053–2061.
- Schoeller D, Gretebeck R. Energy utilization and exercise in spaceflight. In: Lane HW, Schoeller DA, eds. *Nutrition in Spaceflight and Weightlessness Models*. Boca Raton, Fla: CRC Press; 2000:97–118.
- LeBlanc A, Lin C, Shackelford L, et al. Muscle volume, MRI relaxation times (T2), and body composition after spaceflight. *J Appl Physiol*. 2000;89:2158–2164.
- LeBlanc A, Rowe R, Schneider V, Evans H, Hedrick T. Regional muscle loss after short duration spaceflight. *Aviat Space Environ Med*. 1995;66:1151–1154.
- Schneider SM, Amonette WE, Blazine K, et al. Training with the International Space Station interim resistive exercise device. *Med Sci Sports Exerc*. 2003;35:1935–1945.
- Shackelford LC, LeBlanc AD, Driscoll TB, et al. Resistance exercise as a countermeasure to disuse-induced bone loss. *J Appl Physiol*. 2004;97:119–129.
- Johnston RS, Dietlein LF, eds. *Biomedical Results From Skylab (NASA SP-377)*. Washington, DC: National Aeronautics and Space Administration; 1977.
- Stein TP, Leskiw MJ, Schluter MD, Donaldson MR, Larina I. Protein kinetics during and after long-duration spaceflight on Mir. *Am J Physiol*. 1999;276:E1014–E1021.
- Ferrando AA, Lane HW, Stuart CA, Davis-Street J, Wolfe RR. Prolonged bed rest decreases skeletal muscle and whole body protein synthesis. *Am J Physiol*. 1996;270(4 pt 1):E627–E633.
- Ferrando AA, Tipton KD, Bamman MM, Wolfe RR. Resistance exercise maintains skeletal muscle protein synthesis during bed rest. *J Appl Physiol*. 1997;82:807–810.
- Zwart SR, Davis-Street JE, Paddon-Jones D, Ferrando AA, Wolfe RR, Smith SM. Amino acid supplementation alters bone metabolism during simulated weightlessness. *J Appl Physiol*. 2005;99:134–140.
- Zwart SR, Smith SM. The impact of space flight on the human skeletal system and potential nutritional countermeasures. *Int Sportmed J*. 2005;6:199–214.
- Holick MF. Microgravity-induced bone loss—will it limit human space exploration? *Lancet*. 2000;355:1569–1570.
- LeBlanc A, Schneider V, Shackelford L, et al. Bone mineral and lean tissue loss after long duration space flight. *J Musculoskelet Neuron Interact*. 2000;1:157–160.
- Lang T, LeBlanc A, Evans H, Lu Y, Genant H, Yu A. Cortical and trabecular bone mineral loss from the spine and hip in long-duration spaceflight. *J Bone Miner Res*. 2004;19:1006–1012.
- Smith SM, Nillen JL, Leblanc A, et al. Collagen cross-link excretion during space flight and bed rest. *J Clin Endocrinol Metab*. 1998;83:3584–3591.
- Smith SM, Wastney ME, O'Brien KO, et al. Bone markers, calcium metabolism, and calcium kinetics during extended-duration space flight on the Mir space station. *J Bone Miner Res*. 2005;20:208–218.
- Zwart SR, Hargens AR, Smith SM. The ratio of animal protein intake to potassium intake is a predictor of bone resorption in space flight analogues and in ambulatory subjects. *Am J Clin Nutr*. 2004;80:1058–1065.
- Smith SM, Wastney ME, Morukov BV, et al. Calcium metabolism before, during, and after a 3-mo spaceflight: kinetic and biochemical changes. *Am J Physiol*. 1999;277(1 pt 2):R1–R10.
- Smith SM, Davis-Street JE, Feserman JV, et al. Evaluation of treadmill exercise in a lower body negative pressure chamber as a countermeasure for weightlessness-induced

- bone loss: a bed rest study with identical twins. *J Bone Miner Res.* 2003;18:2223–2230.
26. Pence BC, Yang TC. Antioxidants: radiation and stress. In: Lane HW, Schoeller DA, eds. *Nutrition in Spaceflight and Weightlessness Models*. Boca Raton, Fla: CRC Press; 2000:233–252.
 27. Curtis SB, Vazquez ME, Wilson JW, Atwell W, Kim M, Capala J. Cosmic ray hit frequencies in critical sites in the central nervous system. *Adv Space Res.* 1998;22: 197–207.
 28. Kennedy AR, Ware JH, Guan J, et al. Selenomethionine protects against adverse biological effects induced by space radiation. *Free Radic Biol Med.* 2004;36:259–266.
 29. Hong MY, Bancroft LK, Turner ND, et al. Fish oil decreases oxidative DNA damage by enhancing apoptosis in rat colon. *Nutr Cancer.* 2005;52:166–175.
 30. Johnston RS, Dietlein LF, Berry CA, eds. *Biomedical Results of Apollo (NASA SP-368)*. Washington, DC: National Aeronautics and Space Administration; 1975.
 31. Smith MC, Berry CA. Dinner on the moon. *Nutr Today.* 1969;4:37–42.
 32. Smith MC, Huber CS, Heidelbaugh ND. Apollo 14 food system. *Aeros Med.* 1971;42:1185–1192.
 33. Johnston RS, Dietlein LF, eds. *Biomedical Results From Skylab (NASA SP-377)*. Washington, DC: National Aeronautics and Space Administration; 1977.
 34. Bourland C, Kloeris V, Rice B, Vodovotz Y. Food systems for space and planetary flights. In: Lane HW, Schoeller DA, eds. *Nutrition in Spaceflight and Weightlessness Models*. Boca Raton, Fla: CRC Press; 2000:19–40.
 35. Perchonok M, Bourland C. NASA food systems: past, present, and future. *Nutrition.* 2002;18:913–920.
 36. Ogren WL. Photorespiration: pathways, regulation, and modifications. *Annu Rev Plant Physiol.* 1984;35:415–442.
 37. Drake BG, Gonzalez-Meler MA, Long SP. More efficient plants: a consequence of rising atmospheric CO₂? *Annu Rev Plant Physiol Plant Mol Biol.* 1997;48:609–639.
 38. Daunicht HJ, Brinkjans HJ. Gas exchange and growth of plants under reduced air pressure. *Adv Space Res.* 1992;12:107–114.
 39. Rygalov VY, Fowler PA, Wheeler RM, Bucklin RA. Water cycle and its management for plant habitats at reduced pressures. *Habitation.* 2004;10:49–59.

USDA Food Programs Reach Record Cost

The cost of USDA Food Assistance Programs reached almost \$53 billion in FY 2006, a 4% increase and a historical record, according to a report released on February 13 by the USDA Economic Research Service, titled “*The Food Assistance Landscape: FY 2006 Annual Report*.” The report notes that Federal expenditures for USDA’s food assistance programs totaled almost \$53 billion in fiscal 2006, a 4% increase over the previous fiscal year. This was the sixth consecutive year in which food assistance expenditures increased and the fourth consecutive year in which they exceeded the previous historical record. The 5 largest food assistance programs, the Food Stamp Program;

the National School Lunch Program; the Special Supplemental Nutrition Program for Women, Infants, and Children (WIC); the Child and Adult Care Food Program; and the School Breakfast Program, accounted for 95% of USDA’s total expenditures for food assistance. This report uses preliminary data from the Food and Nutrition Service to examine trends in the programs in fiscal 2006. It also discusses a recent Economic Research Service study that examined income volatility among households with children and the implications of volatility for eligibility in the National School Lunch Program. A full copy of the report is posted at <http://www.ers.usda.gov/Publications/EIB6-4/>. Source: USDA